Radiative shocks at PALS and links to astrophysics

Chantal Stehlé

LERMA, Observatoire de Paris, UPMC, CNRS, France

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The "**Integrated Initiative**" of European Laser Infrastructures in the 7th Framework Programme of the European Union

Radiative shocks in astrophysics and in the laboratory

Radiative shocks are complex flows, which occur in many astrophysical situations

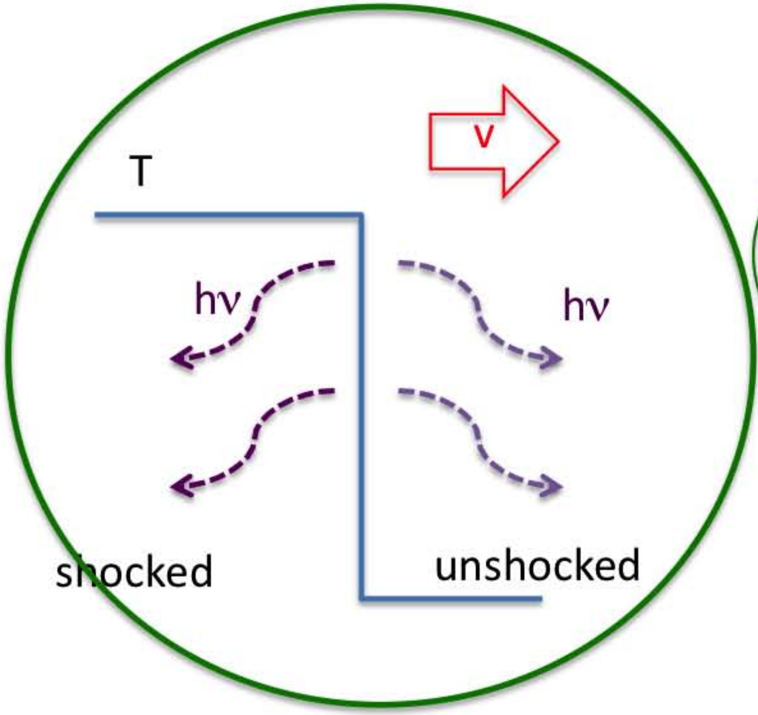
Experiments are necessary :

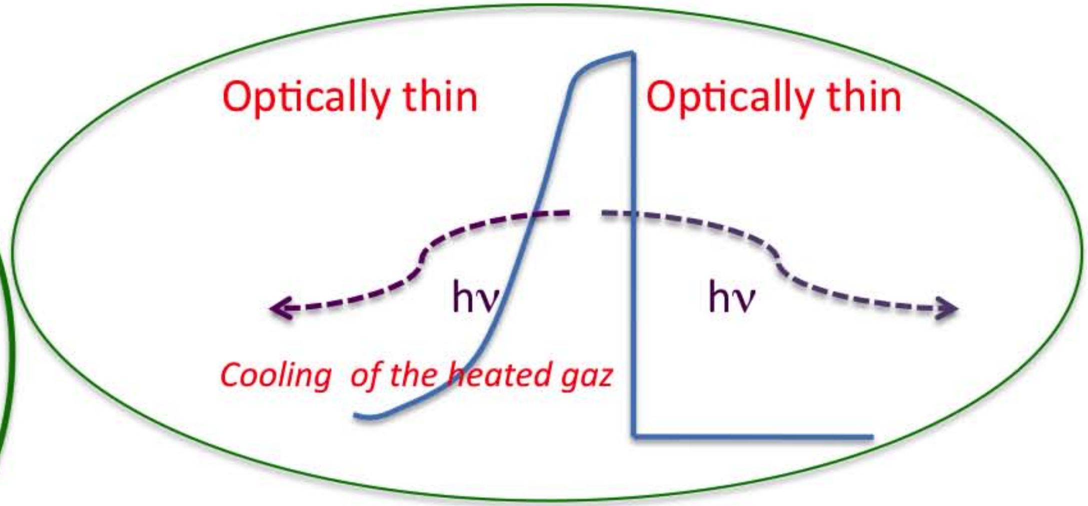
- to study shocks
  which are in the same physical regime than their astrophysical analogues

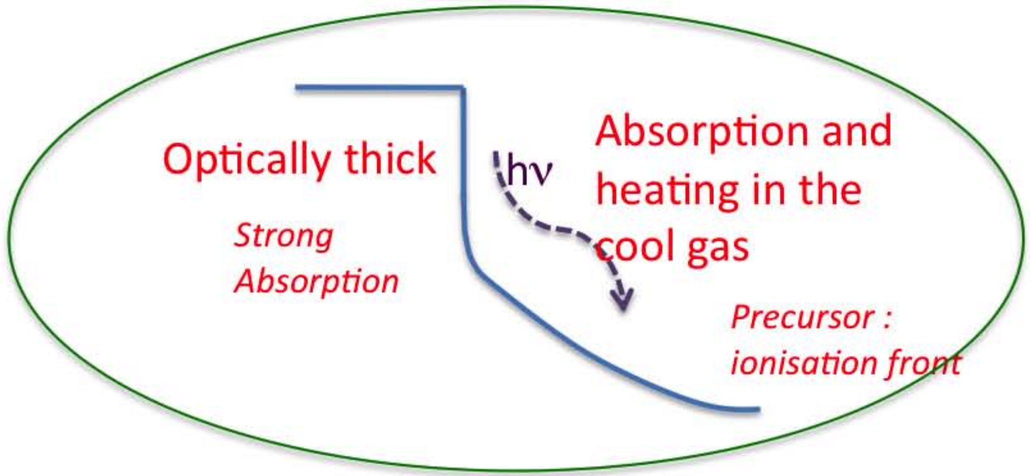
- to give benchmark for the numerical simulations,
  which will be used to simulate astrophysical flows.

Radiative shocks

- Strong shocks which are structured by radiation



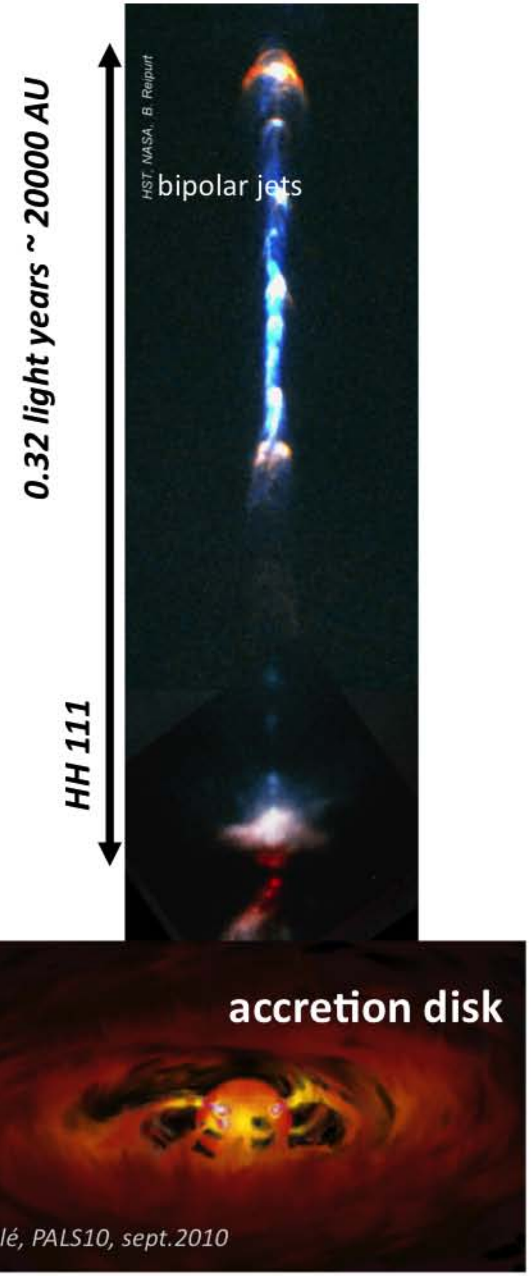




T_{shock} (K) ~ v_{shock}^2

The question of accretion shocks in Young Stars

Stellar accretion shock in Classical T-Tauri Stars



See for instance Bouvier & al.
in Protostars & Planets, 2009

- low mass ($M \sim 1\text{-} 2\ M_\odot$)
- young ($\sim 10^6$ yrs) stars
- slow rotators (10-20 km/s)
- spectroscopic & photometric variability
- UV & IR excesses, X ray emission
- B ~1-2 kG , spots.

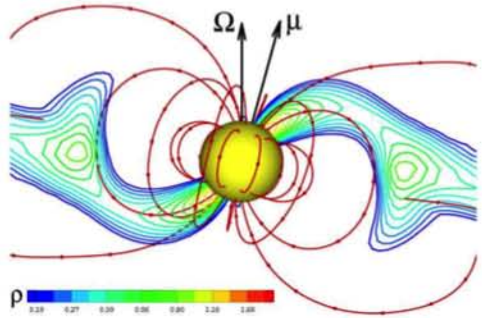
- **accretion disk & huge bipolar jets (100 km/s, parsec)**

Accretion occurs along <u>3D</u> structures connecting the disk to the star ($10^{-6}\ M_\odot$/yr) :

- Magnetospheric columns

Stellar accretion shock in CTTs

From Romanova et al., ApJ 2006



- Dynamics of the accretion flow : free fall velocity $v \sim (2\,GM/R)^{0.5}$ -> **400 km/s**

From Gunther et al 2007

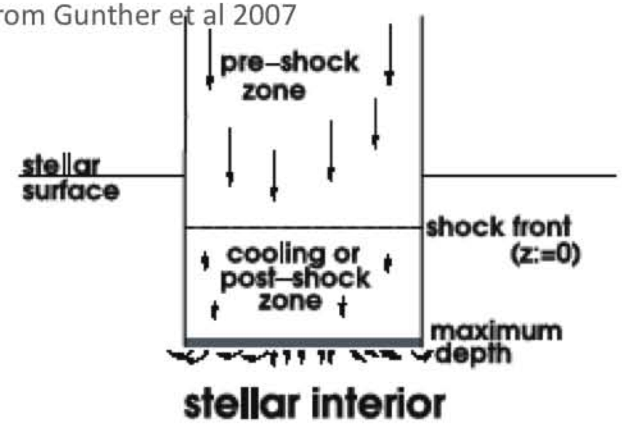


Fig. 1. Sketch illustrating the structure on the accretion column. In the stellar atmosphere a thin standing shock front forms followed by a radiative cooling zone.

Accretion shock is close to the surface

Highly supersonic : M = 70 (*for $T_* \sim 5000$ K*)

Temperature $T_{shock} \sim 1.5\ 10^5\ (v/100)^2 \sim$ **$2.\ 10^6$K**

Depending on the opacity and thus on the shock location, the structure and signature of the shock may differ

(presence of a radiative precursor)

Experimental studies of (*non optically thin*) radiative shocks

The objective is to obtain

(1) strong sustained shocks (M>>1) in gases

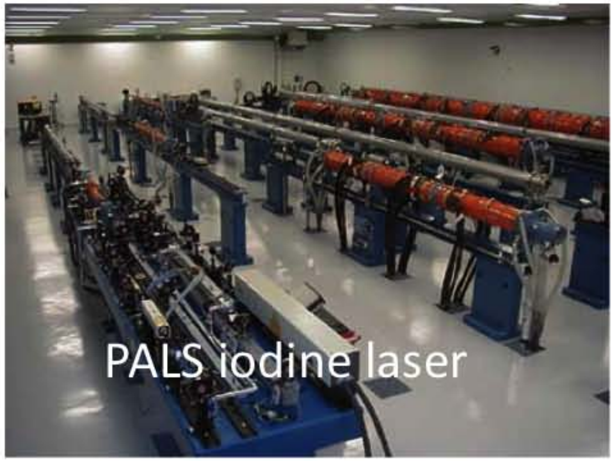
(2) with a strong impact of the radiation.

(3) in the simplest geometry (1D)

(4) on laboratory scales

This has been achieved on high energy laser installations, like :

LULI (60J, 1ns), PALS (200 J, 0.3 ns) and Rochester (4000J, 1ns)



Bouquet et al, PRL 2004,
Gonzalez et al., LPB 2006
Reighard et al. PoP 2007

Typical setup

-> **1D geometry**: cylindric or parallelepipedic target (mm scale)

-> shock launched by a piston with ~ **constant velocity**

-> **high Z gas (xenon)** favorable to radiation

-> **moderate/low pressures** $\rho \sim 10^{-4}$ g/cm^3 (opacity adjustments)

$\tau = 1$ (for 1 mm, xenon @ 300K) -> $\rho = 5\ 10^{-4}$ g/cm^3 (0.1 bar)

PALS target (1mm^2, 4mm)

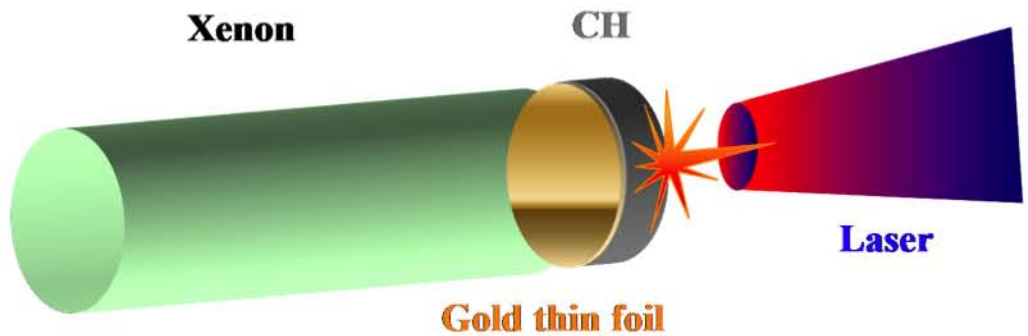
Stehlé, PALS10, sept.2010

LULI	**60 km/s**	5 10^{-4} g/cm^3	60 J, 1ns
PALS	**55 km/s**	5 10^{-4} g/cm^3	200 J, 0.3 ns
Rochester	**>100 km/s**	6 10^{-3} g/cm^3	4000 J, 1 ns

Bouquet et al, PRL 2004,
Gonzalez et al., LPB 2006
Reighard et al. PoP 2007

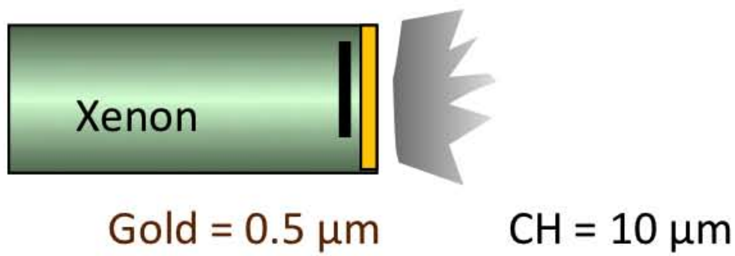
Principle of radiative shock generation

The laser is focalized on a foil which converts the radiation energy into mechanical energy.



Target

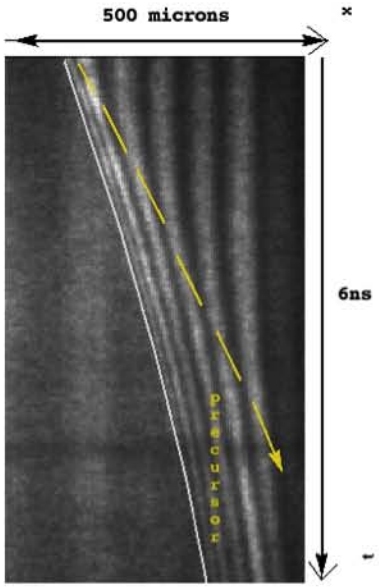
Millimetric scales,



Where are we ?

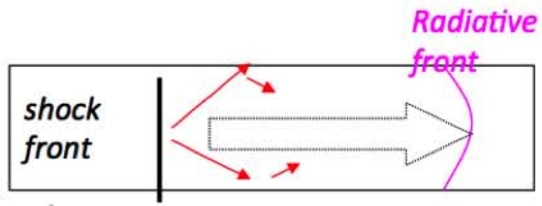
Summary of the main achievements

(a selection)

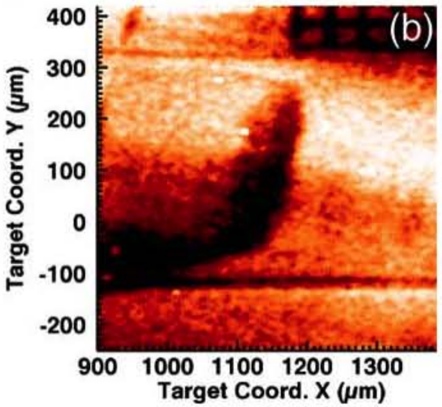


2000 @ LULI and after :

Precursor dynamics over 6 ns : visible time resolved interferometry
Shock velocity (60 km/s)
-> 2D effects in the precursor :
radiation losses on the windows
reduce the velocity of the precursor



(Fleury et al, LPB 2002, Bouquet et al PRL 2005, Leygnac et al. 2



2006 @ Rochester :

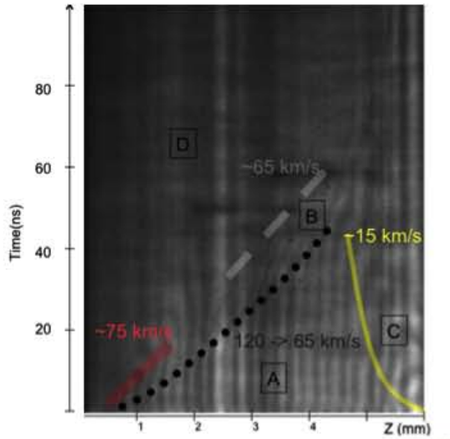
Shock front :

Shock velocity (~ 100-150 km/s)
Te ≠ Ti in the shock front: visible Thomson scattering,
The shock front is plane : point source X ray imaging

(Reighard et al. POP 2006)

Summary of the main achievements

(a selection)



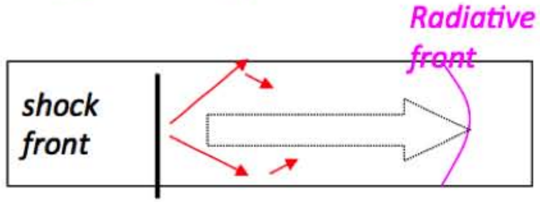
2005 and 2007 @ PALS :

Precursor dynamics over 50 ns :

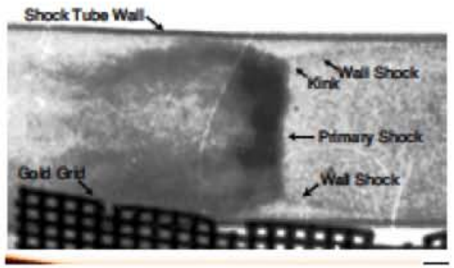
visible time resolved shadowgraphy & interferometry .

-> Lateral radiative losses affect the long time dynamics of the precursor.

-> Bending of the ionisation front



(Gonzalez et al. 2005, Stehlé et al 2010)



2009 @ Rochester :

Shock front: point source X ray imaging

Radiation from the front may ablate the window: this leads to perturbations near the front shock.

(Doss et al. 2009)

What about PALS experiments ?

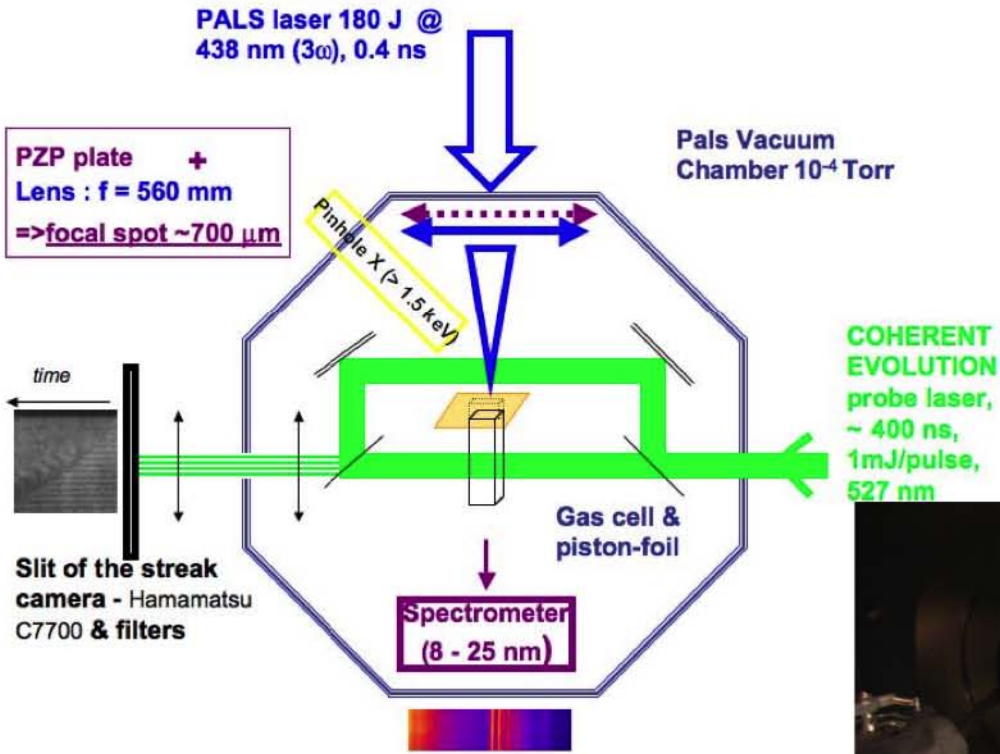
Experiments @ PALS

General motivations :

1- is the shock stable over long times?
2- is the quasi stationnary limit reachable ?
3- what is the structure of the precursor, shock and post shock ?
4- what are the photometric and spectroscopic signatures of the structure ?

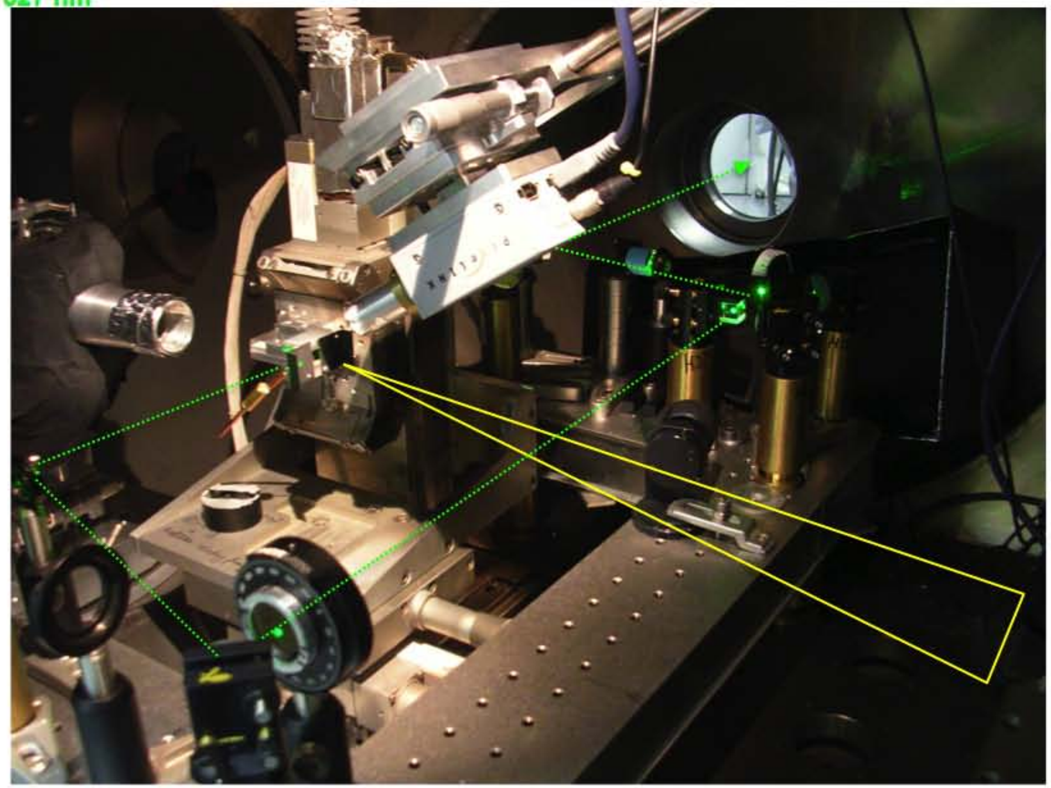
PALS 2007

Experimental Setup



Visible interferometry to probe Ne in the precursor over long times .

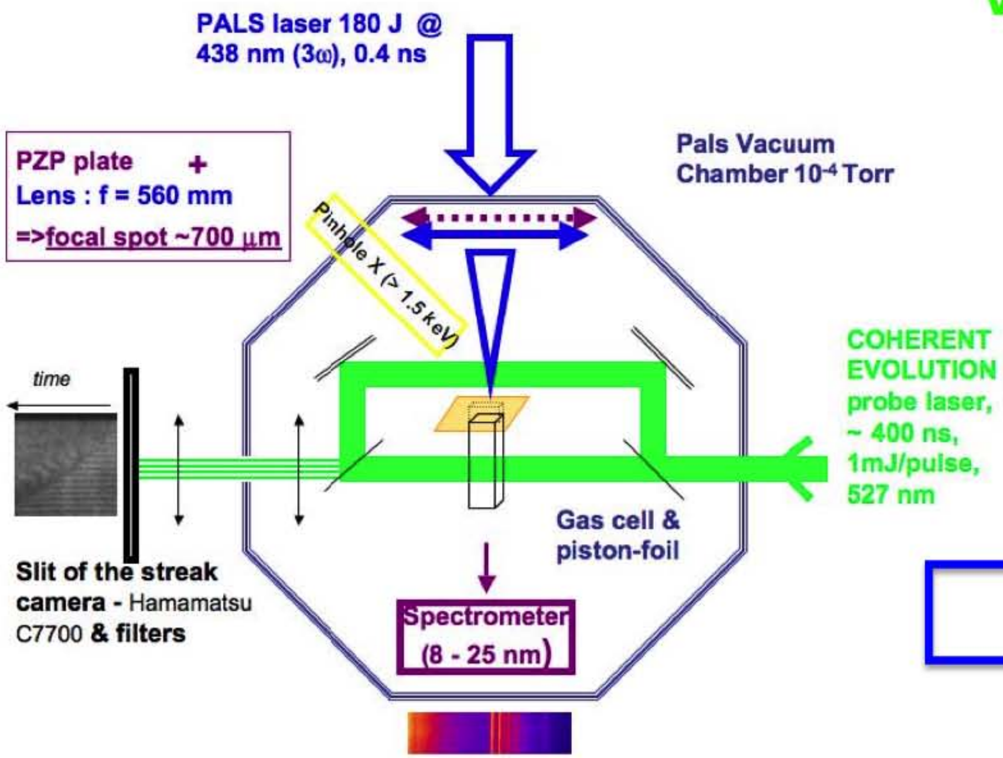
Backside XUV spectroscopy
(exploratory work)



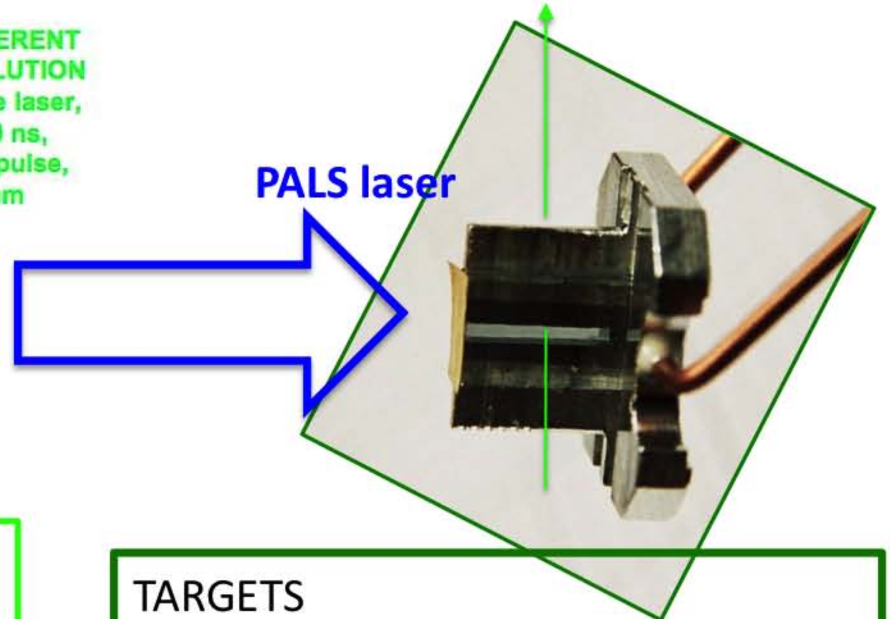
C.Stehlé, M. González, M. Kozlova, B. Rus, T. Mocek, O. Acef, J. P. Colombier, T. Lanz, N. Champion, K. Jakubczak, J. Polan, P. Barroso, D. Bauduin, E.Audit, J. Dostal, M. Stupka, «Experimental study of radiative shocks at PALS facility ", LPB 2010

Experimental Setup

Visible interferometry



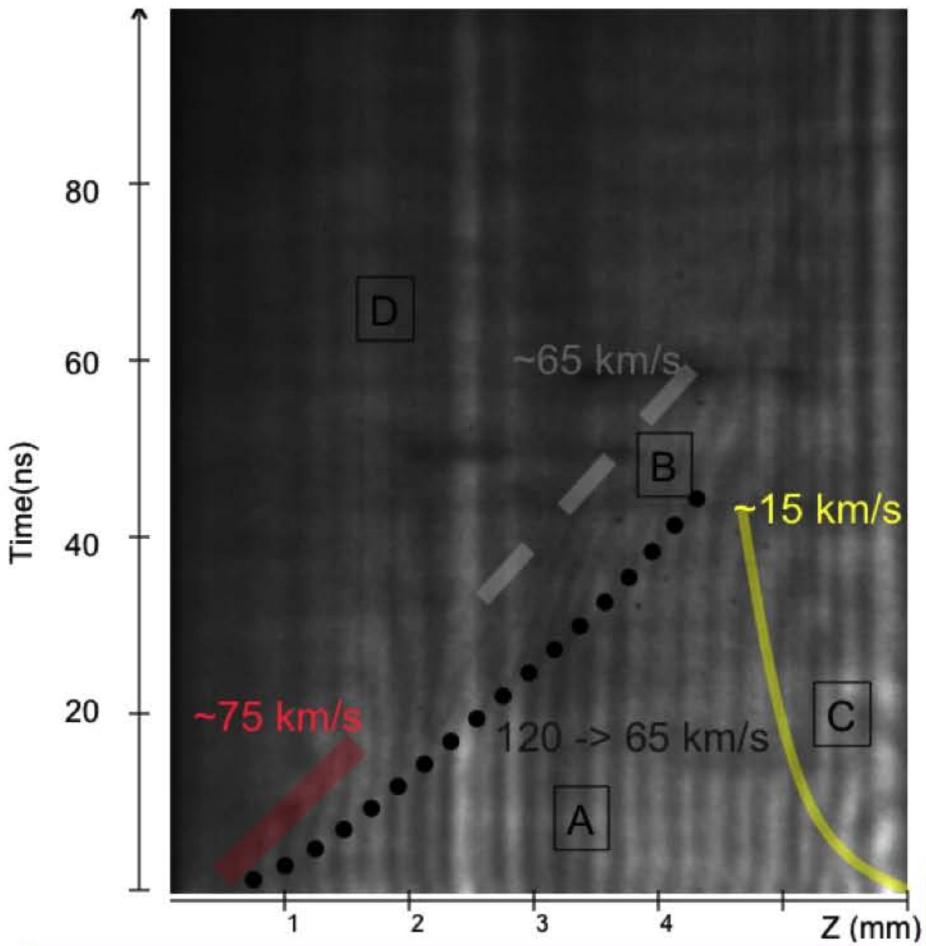
Xe : 0.1 bar

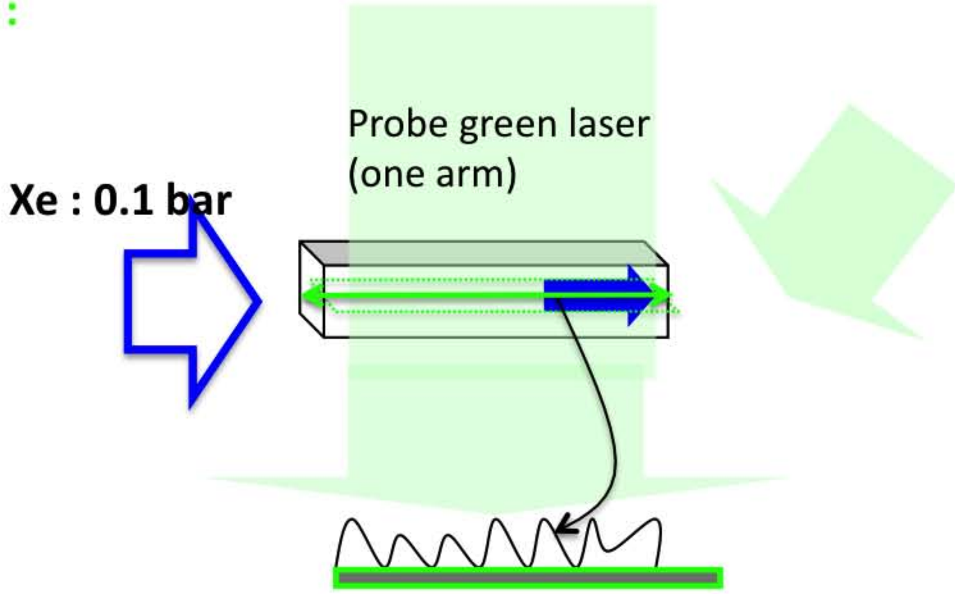


Mach Zehnder setup (SYRTE, Obs de Paris)
with 2 configurations :
- slit of the Streak Camera // direction of shock propagation (***longitudinal interferometry***)
- slit ⊥ direction of shock propagation (***transverse interferometry***)

TARGETS
(*Pôle Instrumental Obs. de Paris*):
channel 0.6 x 0.6 x 6 mm3
BK7 windows (aluminium coating)

Time Resolved Longitudinal interferometry : extension and dynamics of the precursor





Streak camera, *slit // shock propagation*

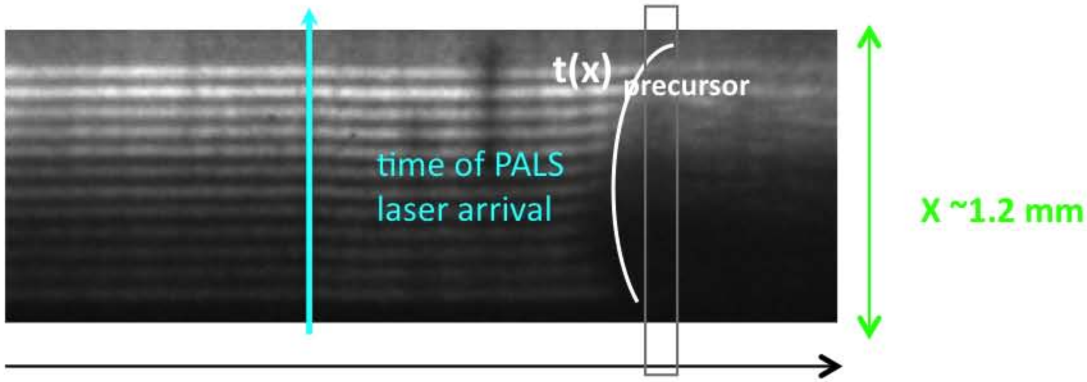
it is known that (*Gonzalez et al., A&A 2009*) :
- the time needed to reach the quasi-stationary limit depends on radiative losses at the walls
- the extension of the precursor, also depends on these losses

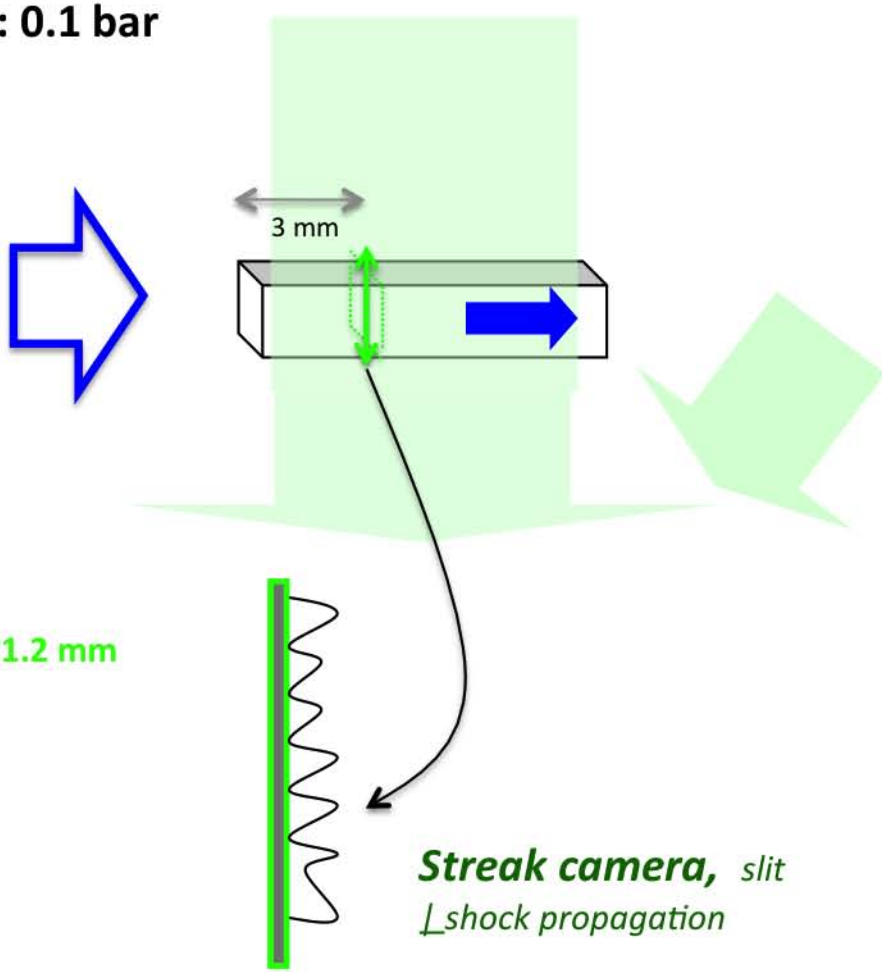
~ quasitationary limit , v shock ~ 65 km/s
heating coming back from the rear face

Here :
- time needed to reach the quasi-stationary limit t ~ 40 ns for **40% losses**
- The extension of the precursor is also consistent with **40% losses**

Time Resolved Transverse interferometry : deformation of the precursor

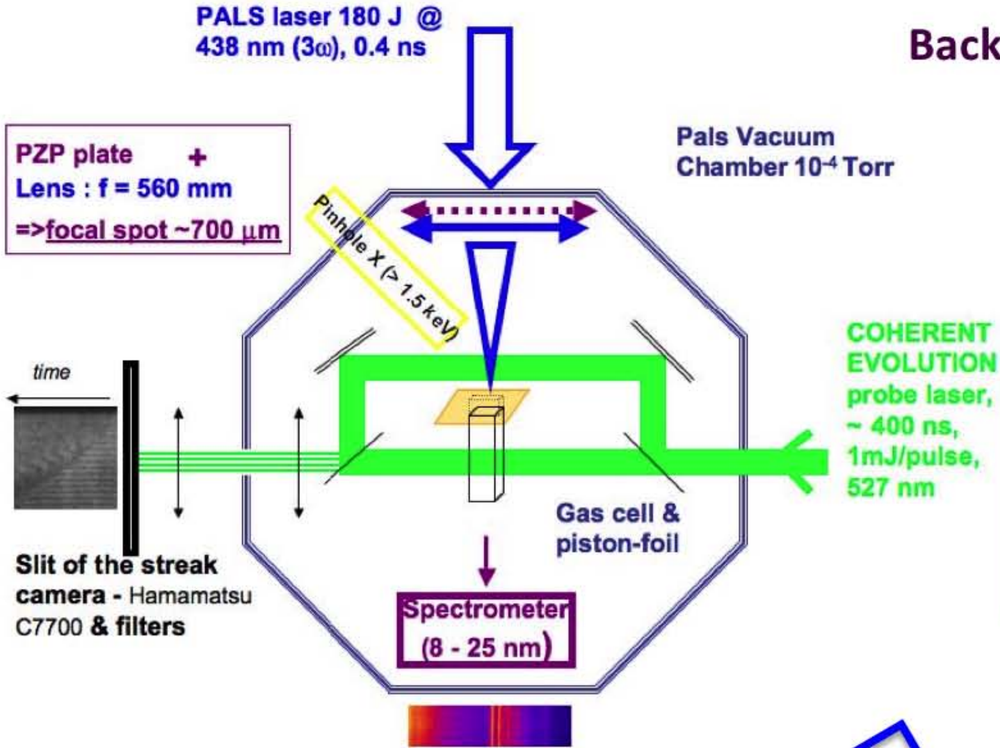
Xe : 0.1 bar





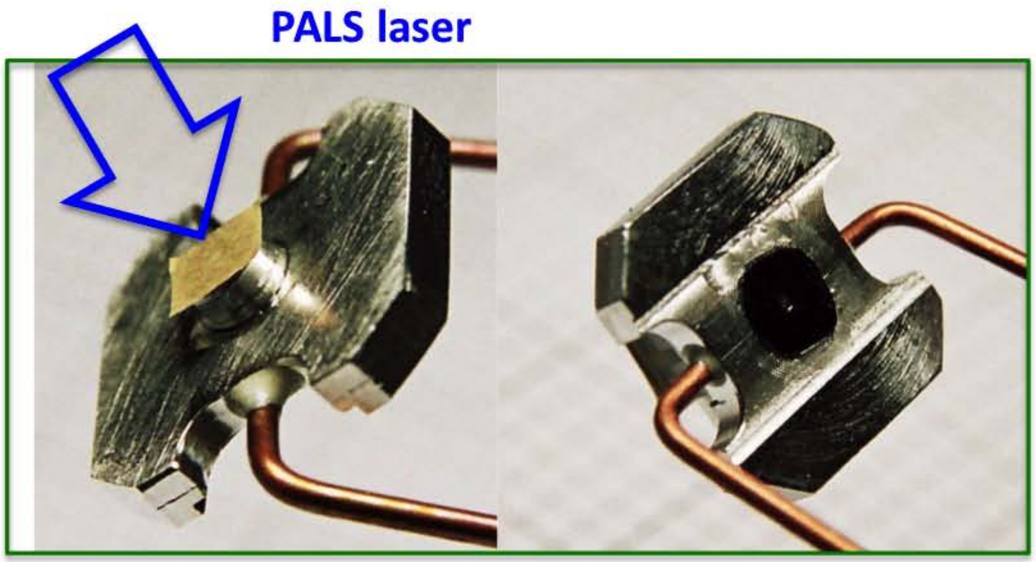
Confirmation of the bending of the radiative precursor, due to the radiative losses

Experimental Setup

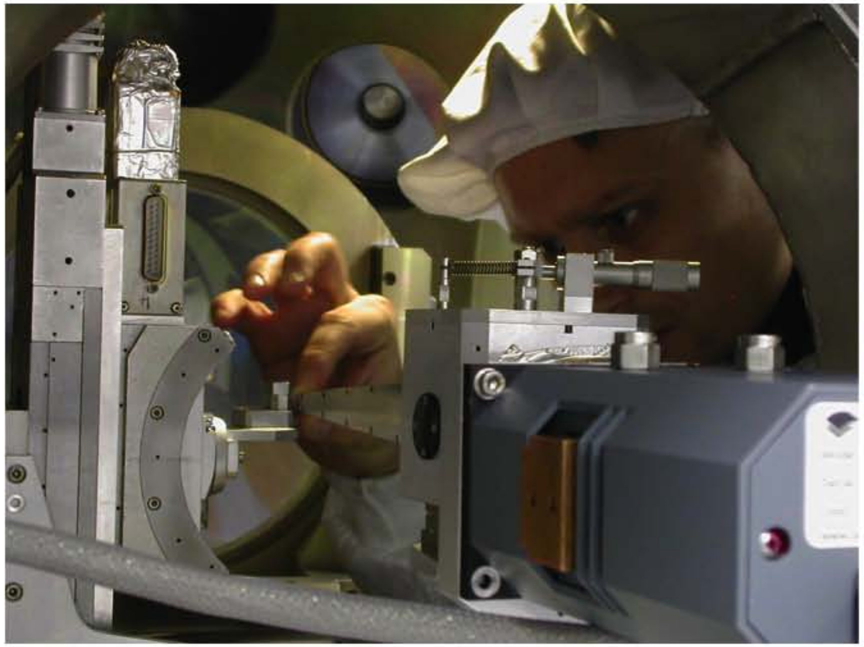


Backside XUV spectroscopy
(exploratory work)

TARGETS :
- blind and short channel
- XUV window
  (SiC, made by LPN France or Al foil made by Luxel)



Flat field XUV spectrometer (XRL dpt Prague) **Time integrated spectrum**

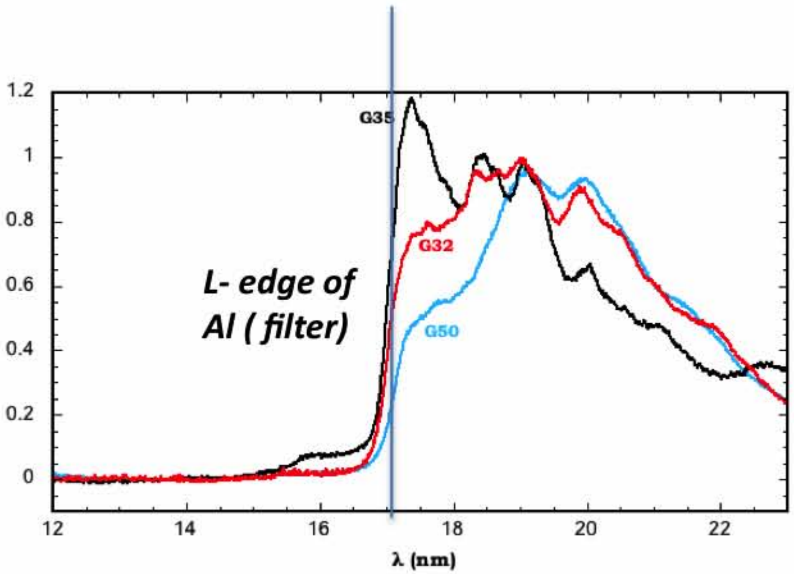


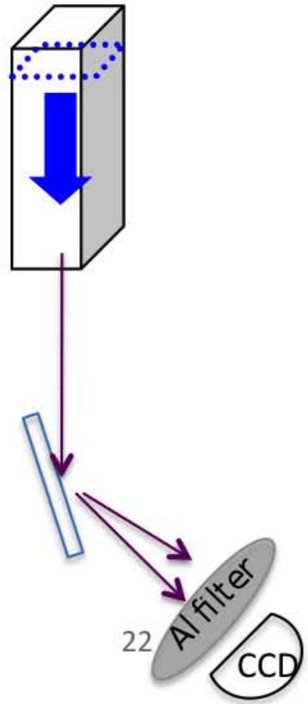
Backside XUV spectroscopy (exploratory work)

Spectroscopic signatures for targets with short shock tubes (L< 3mm). **However difficult :**
- Absorption by the cold xenon,
- Pollution by the walls,

-> other solutions to explore

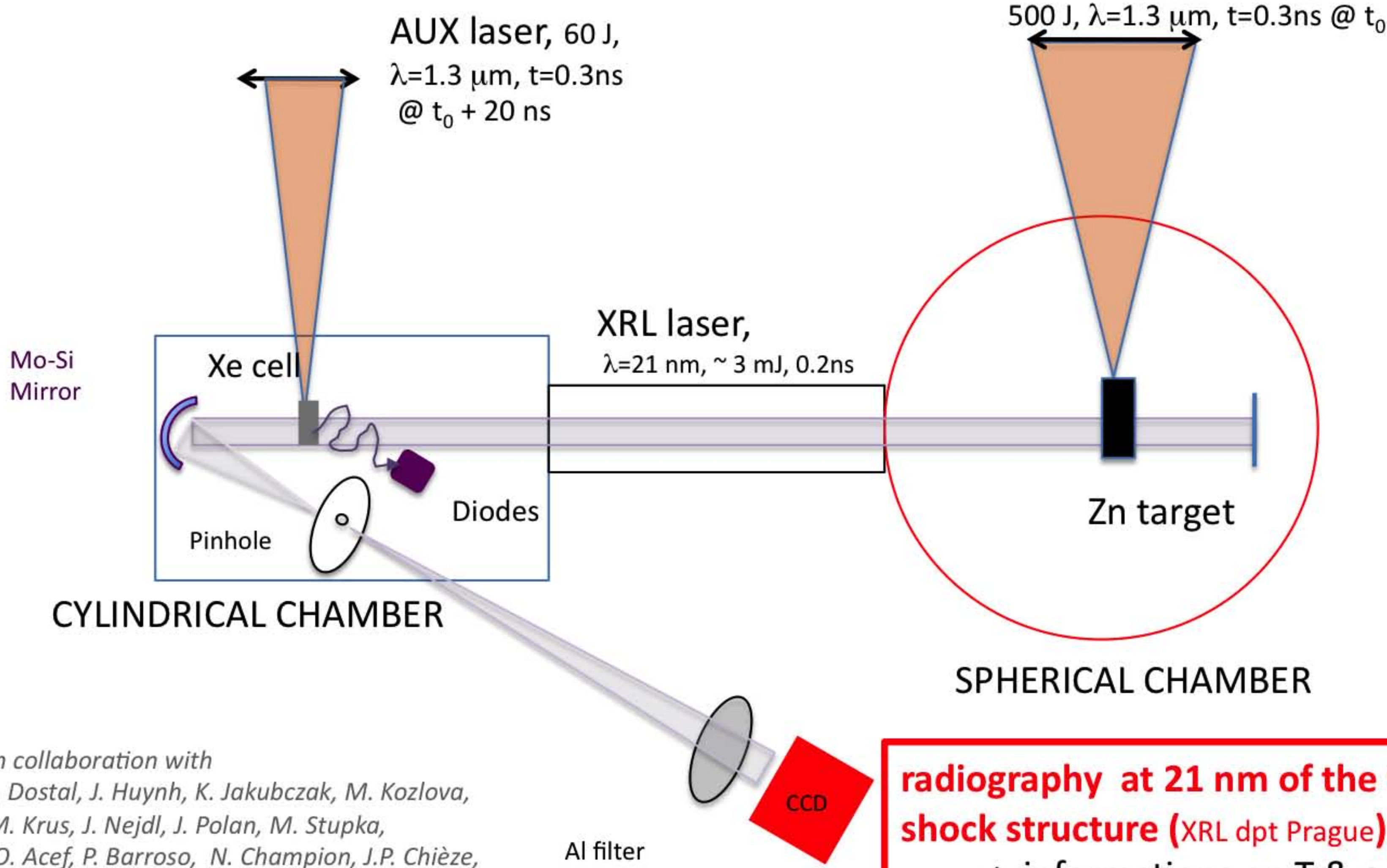
Xe : 0.1 -0.2 bar





PALS 2010

Experimental Setup



In collaboration with
J. Dostal, J. Huynh, K. Jakubczak, M. Kozlova,
M. Krus, J. Nejdl, J. Polan, M. Stupka,
O. Acef, P. Barroso, N. Champion, J.P. Chièze,
P. A Delattre, J. Larour, F. Reix, F Suzuki-Vidal,

NOT TO SCALE !

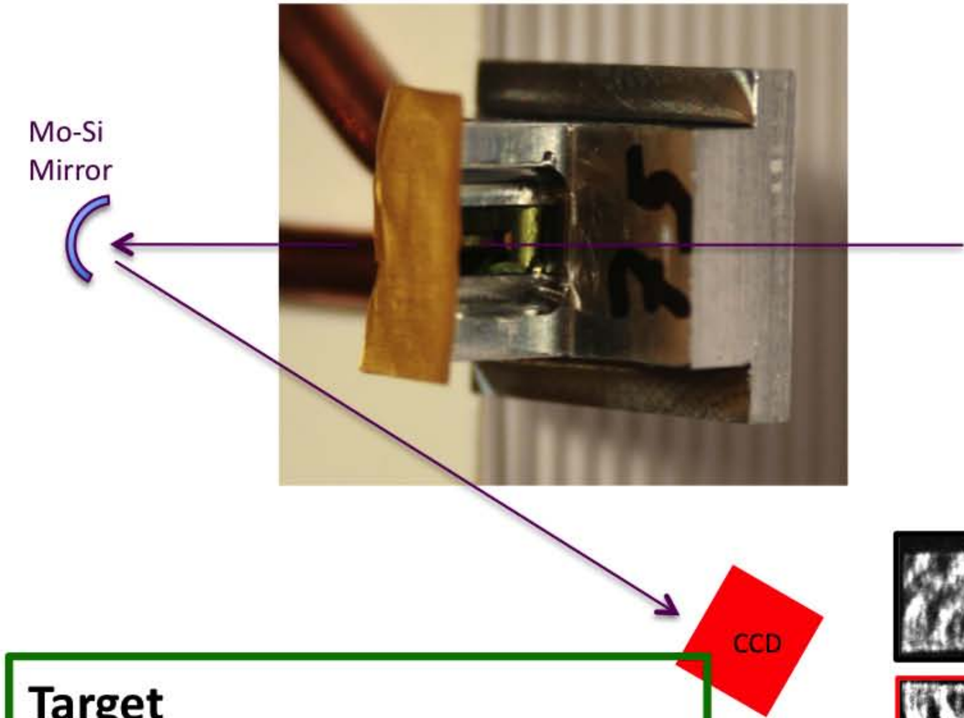
radiography at 21 nm of the whole shock structure (XRL dpt Prague**):**
-> informations on T & ρ

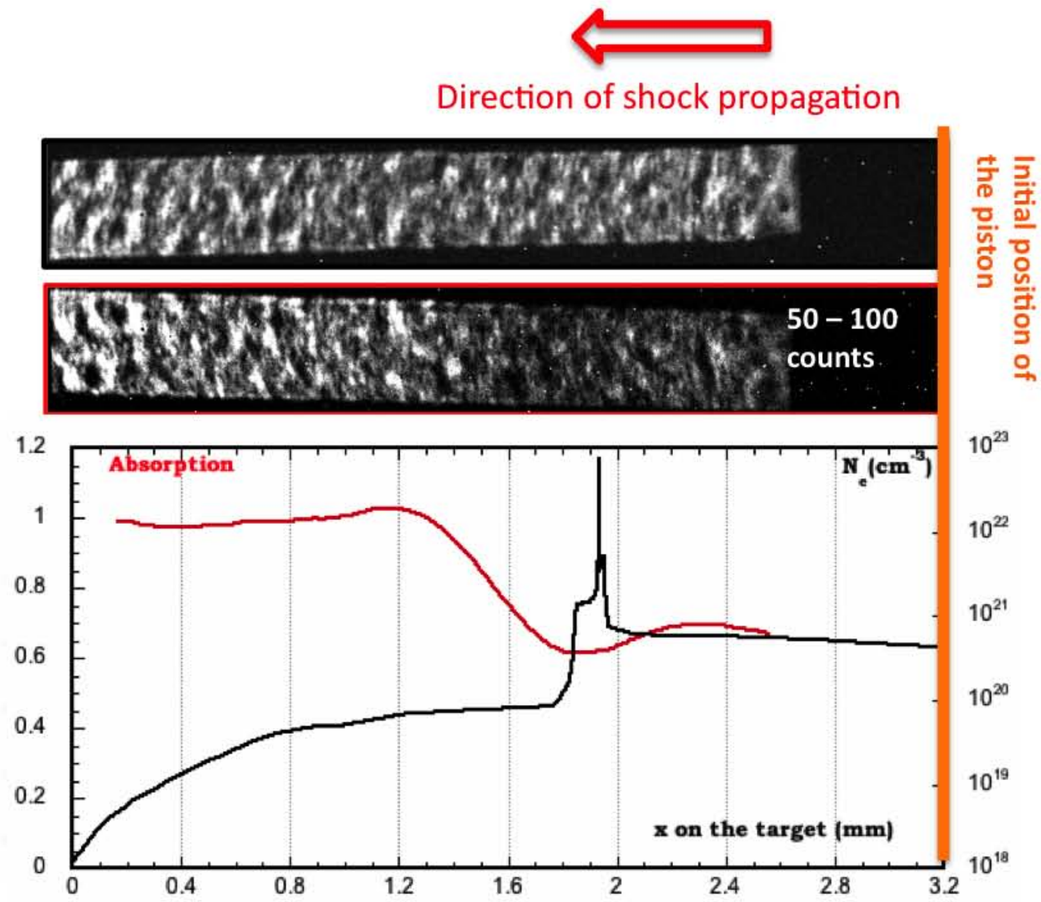
High Speed Si diodes (Obs Paris & LPP**) :**
shock timing

XUV radiography

0.3 bar Xe

Observation of the imprint of the shock in the XUV image 20ns after the shock launching

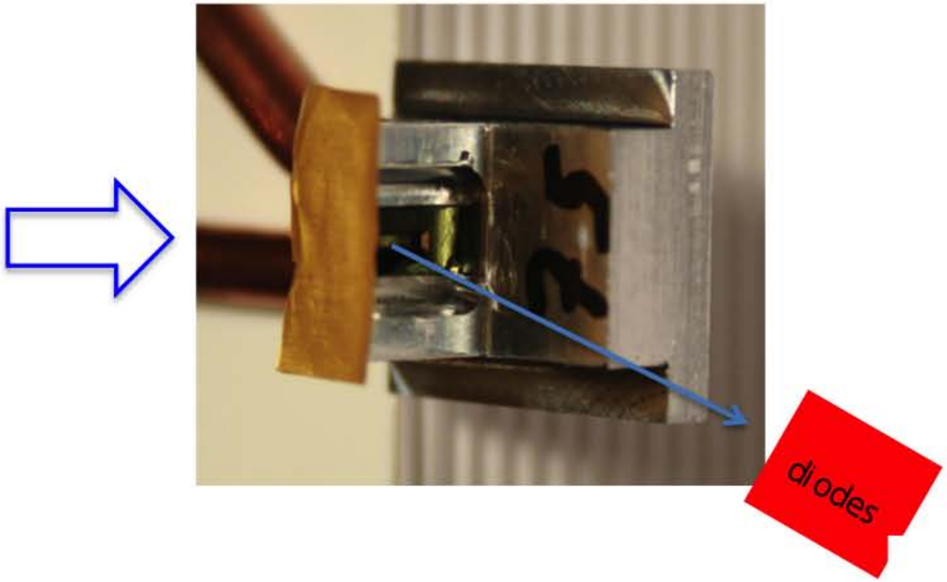




Target
(Pôle Instrumental Obs. de Paris**):**
two Si3N4 windows
T ~ 10^{-3} @ 21 nm

Limitations in the image quality due to the Mo-Si mirror

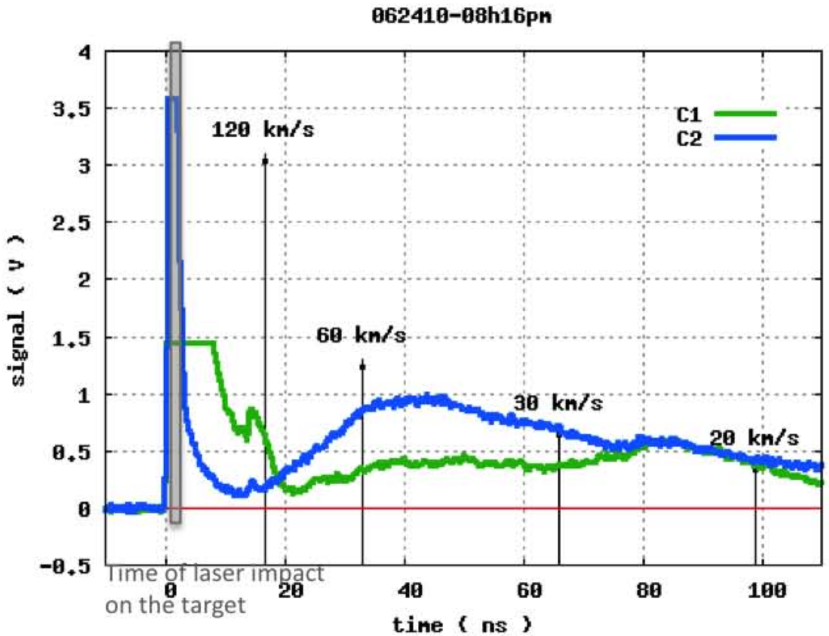
High Speed Si diode diagnostics



Shock velocity ~ 50 km/s, consistent with the previous image

Resolution defined by the pinhole size and geometric considerations :
-> *signal recorded from a section of ~ 0.3 x 0.4 mm², located at 2 mm from the initial position of the piston*

0.3 bar Xe



PERSPECTIVES

Radiative shock waves :

A long way to understand them correctly in laboratory … and in space….

-> Interesting possibilities with XRL probing : access to both front and precursor improvements to perform.
-> The spectroscopic study is difficult, we will start with large band photometry

PALS :
Excellent installation
Excellent and kind support
Unique expertise

Adding an amplifier would be suitable in the context of developing adequate XRL probing of larger plasmas in the context of bigger installations : large plasmas have more absorption ; they also need more power for being generated.

Thanks to J. Ullschmied and all the operational team !